III. ROADSIDE DATA ANALYSIS

A. Introduction

The intent of random roadside inspections is to collect tailpipe (exhaust) emissions data to evaluate overall performance of the Enhanced I/M program and to compare this data to that collected at licensed Smog Check stations. In 1997, BAR initiated its most comprehensive roadside inspection program to date using the Acceleration Simulation Mode (ASM or “loaded-mode”) test protocol which is the same test performed in licensed smog inspection stations. We have used the results of BAR’s roadside inspections to evaluate the effectiveness of California’s Enhanced I/M program. Because roadside data assesses in-use vehicles, the effects of repair effectiveness, inspection and repair prior to an official Smog Check (to avoid failing the test – also known as “pre-inspection and pre-repair”), and fraud are accounted for in the collected data. Therefore, there are no assumptions needed to evaluate the program. It is this aspect that separates the random roadside evaluation methodology from other program evaluation methodologies and emissions models. ARB and BAR staff believe that roadside data analysis provides the most accurate means of determining the effectiveness of the Smog Check II program.

With the assistance of the California Highway Patrol, BAR conducts roadside pullover inspections of randomly selected vehicles at designated locations in Enhanced I/M program areas. At each inspection site, BAR personnel inspect these vehicles on a portable dynamometer using the ASM test protocol. The ASM test consists of two portions, one in which the vehicle is operated at 25 percent load and 25 miles per hour (ASM 2525) and one in which the vehicle is operated at 50 percent load and 15 miles per hour (ASM 5015). The results of each inspection are collected by BAR and are used to evaluate the Enhanced I/M program.

Although BAR began collecting roadside test data in February 1997, only the most recent data – collected November 11, 1998 through October 29, 1999 – are used in this analysis. The data set includes 9,434 total test records. This data provides a unique opportunity to compare vehicles that *have been* tested at a Smog Check station with a loaded-mode test (“After ASM”) to those that *have not received* an ASM inspection ("Before ASM"). It is important to note that the two data sets were collected during the same timeframe and the vehicles are of the same vintage. Unfortunately, this will not be the case for future roadside studies because most, if not all, vehicles will have been through at least one cycle of Enhanced I/M.

The above referenced Before/After data set was also chosen because the total roadside data set (approximately 27,080 test records) was collected over a two and a half year period. Due to emission controls degradation, vehicles of the same model year tested at the beginning of the period may not be comparable to the same model year vehicle being tested at the end of the period. Even the Before/After data set is affected by degradation over the approximate 12-month collection period and the Before data set is probably more impacted than the After data set. However, we believe that the impact on the analysis due to degradation of emissions controls over the data collection period is minimal.

Using California's Vehicle Information Database (VID) records, the roadside data was separated into two groups:

- Vehicles which had completed the ASM test requirement. These are vehicles which had either passed the ASM test at a Smog Check station or had failed an ASM test at a Smog Check station. These vehicles were assumed to have completed the Enhanced I/M requirements and were designated as "After ASM." This group consists of 4,064 test records.

- Vehicles which had <u>not</u> completed an Enhanced vehicle inspection cycle ("Before ASM"). These vehicles had only been tested under the two-speed idle test protocol used prior to implementation of Enhanced Smog Check. This group consists of 5,854 test records.

The roadside data was analyzed to determine the average fleet emissions expressed as concentration (parts per million) and grams per mile (g/mi); and, to determine the percent change in emission rates between the "Before ASM" and "After ASM" vehicle groups.

It is important to note that assumptions about vehicle miles traveled (VMT) and the number of vehicles in each model year (also known as "travel fractions") are the same as used in the draft EMFAC2000 emission model. This specific assumption is made to provide an "apples to apples" comparison to draft EMFAC2000 predictions.

B. <u>Roadside Analysis Disclaimers</u>

The Roadside Inspection Program is intended to provide on-road test data to determine *ASM fleet emission rates* with 95 percent confidence and a relatively small variance. To accomplish this, a "stratified sampling" methodology was used. Stratified sampling ensures that sufficient data from the older model year vehicles are collected to calculate an accurate overall fleet emission rate. In this analysis, model year emission rates are also calculated and shown. However, the variance by model year is generally substantially greater than the fleet average variance. This can be explained by the substantial vehicle-to-vehicle emission differences within model years, and the small sample size in some of the model years. More specifically, the stratified sampling plan did not collect sufficient data in each model year to accurately calculate a model year emission rate with a small variance and high statistical confidence. Therefore, readers are cautioned against improperly using the model year results.

The roadside data were collected between November 11, 1998 and October 29, 1999. From November 11, 1998 to October 3, 1999, the HC, NOx, and CO cut points used in the I/M program remained constant; however, it should be noted that the NOx cut points were set at *gross polluter* levels. On October 4, 1999, BAR lowered the NOx cut points to the levels specified in BAR regulations – this is what is referred to in this report as “current levels.” Therefore, the calculated emissions rates and reductions are not precisely representative of program performance under gross polluter NOx cut points as is generally presented in this report. However, we believe the impact of vehicles that had been tested under the new NOx cut points and repaired, and then tested as part of the roadside program is very small.

In addition, readers are reminded that four independent inspection crews using four sets of test equipment collected the vehicle emission measurements under field, not laboratory, conditions. There may be some non-quantifiable crew-to-crew or equipment-to-equipment bias introduced into the results. However, every effort has been made to minimize this uncertainty.

Also, for purposes of this report, we use only the random roadside inspections for tested gasoline-powered passenger cars and light- and medium-duty trucks weighing less than 8,501 pounds. While heavy-duty trucks were subject to the random roadside inspections (two-speed idle test), the data is not analyzed because the number of these vehicles tested is so small. In addition, only the roadside tailpipe emission data is analyzed. Neither functional nor visual inspection data were available at the time of this report. Therefore, the fleet emission rates presented in this report pertain only to tailpipe emissions for the classes of inspected vehicles. The roadside data available in time for this draft report were not sufficient to evaluate the effectiveness of the gas cap check in reducing evaporative emissions. We therefore used the draft EMFAC2000 model to estimate gas cap effectiveness.

This analysis depends on segregating the roadside data into the “Before/After” data groups. It should be noted that the average time since the last smog inspection for the “Before” data group is not the same as for the “After” group. Because of emission system degradation, this may lead to a slight *over-estimation* of the emissions benefits of the enhanced program. BAR found that about 95% of the checked registration records for the “Before” data set were current compared to about 97% for the “After” data set.

In addition, the roadside analysis does not provide a means to evaluate the impact of those people that avoid the program, i.e., don’t comply with the inspection requirements. This too, can lead to over-estimating the program benefits. Within the data set used in this analysis, BAR checked approximately 70% of the tested vehicles to determine if the vehicle registration was current.

As a simplifying assumption, the calculations for 1999 using roadside data assume that a full biennial cycle of loaded mode testing had occurred by the end of 1999. To the extent that less than a full cycle had been completed by 1999, the calculations may overstate the actual reductions in that year. However, for the 1999 calculations based on roadside, this effect is at least partially offset by the fact that we did not account for the benefits from implementing more stringent NOx cut points in October 1999.

C. Fleet Average ASM Concentrations and Predicted FTP Emission Rates

The roadside ASM testing generates emission data expressed as a concentration (for example, parts per million). However, in order to compare the results to the 1994 SIP, these concentrations must be converted to the gram per mile emissions that would be generated if the vehicle was tested using the Federal Test Procedure (FTP). The FTP is the certification test cycle for new passenger cars and light-duty trucks. The model year emission concentrations and FTP emission rates were then weighted by the draft EMFAC2000 travel fractions to calculate the overall fleet average concentrations. Because older vehicles travel less than newer ones, we must weight the roadside data by the travel fractions to accurately reflect the actual in-use fleet average. Sections D through H describe this process in more detail.

D. Fleet Average ASM Concentrations

A more detailed description of the analysis methodology is included in Section E of this Chapter; however, simply stated, the fleet average ASM concentrations were calculated using the following methodology:

1. Calculate the average ASM concentrations by model year;

2. Multiply the average ASM concentrations for each model year by the respective draft EMFAC2000 travel fraction for that model year; and

3. Sum the products for each model year to determine the overall fleet average concentration for the “Before ASM” and “After ASM” cases.

This methodology was used for HC, NOx, and CO for both the ASM 2525 and ASM 5015 concentrations. Table III-1 and Table III-2 show Before ASM and After ASM fleet average ASM 2525/5015 concentrations by model year, as well as the weighted average fleet emission rate.

Insert Table III-1 on this page.

Insert Table III-2 on this page.

E. Methodology for Fleet Average Emissions Calculation

The following describes the method used to calculate estimates of the fleet ASM concentrations as a function of model year from the individual vehicle ASM concentration measurements of the baseline roadside sample. Roadside sampling was performed for 33 model years from 1966 to 1998 in five metropolitan areas where the vehicle population is subject to Enhanced I/M. In calculating concentration means and uncertainties that describe the vehicle population, we used weighting factors for model year (based on EMFAC2000 travel fractions).

Step 1. Calculate Mean and Variance of the Mean for Each Model Year

For the vehicles for a given model year *y*, the mean emission concentration $\bar{x}(y)$ and variance $s^2(y)$ are given by:

$$\bar{x}(y) = \frac{\sum_{i=1}^{n(y)} x(y)_i}{n(y)}$$

$$s^2(y) = \frac{\sum_{i=1}^{n(y)} \left(x(y)_i - \bar{x}(y)\right)^2}{n(y) - 1}$$

where: $x(y)_i$ = emissions value for the *i*th sampled vehicle in the model year *y*
$n(y)$ = the number of sampled vehicles in the model year *y* .

The error variance of the mean for the emissions of the sampled vehicles in the model year *y* is given by:

$$\mathrm{var}\left(\bar{x}(y)\right) = \frac{s^2(y)}{n(y)}$$

For the model year under consideration, the 95% confidence interval for the mean emissions of the fleet is given by:

$$\bar{x}(y) \pm 1.96 * \sqrt{\mathrm{var}\left(\bar{x}(y)\right)}$$

Step 2. Calculate Travel Fraction Weighted Mean and Variance of the Mean for the Fleet

The model year means and uncertainties for the fleet are then combined to arrive at average emissions estimates for the fleet. The weighting factors are the travel fractions for each model year.

The fleet average emissions $\bar{x}$ weighted by model year travel fractions tf_y is given by:

$$\bar{x} = \frac{\sum_{y=1}^{33} tf_y \, \bar{x}(y)}{\sum_{y=1}^{33} tf_y}$$

where $\bar{x}(y)$ is the average emissions for the model year y.

The error variance of the fleet mean is given by:

$$\mathrm{var}(\bar{x}) = \frac{\sum_{y=1}^{33} tf_y^{\,2} \, \mathrm{var}(\bar{x}(y))}{\left(\sum_{y=1}^{33} tf_y\right)^2}$$

where $\mathrm{var}(\bar{x}(y))$ is the error variance of the mean for model year y.

Finally, the 95% confidence interval on the fleet mean emissions is given by:

$$\bar{x} \pm 1.96\sqrt{\mathrm{var}(\bar{x})}$$

F. Fleet Average Predicted FTP Emissions

The ASM concentrations were converted into predicted FTP rates in g/mi using the latest conversion equations developed by Radian/Eastern Research Group (Radian/ERG). These conversion equations are described in the Radian/ERG report, *Equations for Estimating California Fleet FTP Emissions from ASM Concentrations*, dated December 25, 1999.

Once the model year average predicted FTP emission rates were determined, weighted fleet average FTP emission rates shown in Table III-3 were calculated using the following methodology:

- Calculate average predicted FTP emission rate by model year for each pollutant (HC, CO and NOx);
- Multiply the average predicted FTP emission rate for each model year and pollutant by the EMFAC2000 travel fraction for that model year; and,
- Sum the products for each model year by pollutant to determine the overall fleet average predicted FTP emission rate for each time period.

Table III-3 also shows the percent reduction in HC, CO, and NOx emission rate for each model year, as well as for the overall fleet. The roadside data shows that enhanced I/M in 1999 reduced emission rates of HC by 13 %, NOx by 6 %, and CO by 12 %. Appendix A includes a discussion of the emission reductions achieved in terms of tons per day.

Insert Table III-3 here.

A more detailed description of the methodology used to calculate the predicted FTP emissions follows in Section G.

G. Equations for Estimating California Fleet FTP Emissions

This section describes the method used to calculate estimates of the fleet FTP emission rates as a function of model year from the individual vehicle ASM concentration measurements of the baseline roadside sample. In addition, this section describes the calculation of the estimated uncertainty in mean FTP values. These uncertainties are estimates of the precision of the mean values. They do not include estimates of biases in mean values.

Roadside sampling was performed across 33 model years from 1966 to 1998 and throughout 5 metropolitan areas where the vehicle population is subject to enhanced I/M. In calculating emission rate means and uncertainties that describe the vehicle population, weighting factors for model year (based on travel fraction) were used.

Step 1. Convert ASM Concentrations to FTP Emission Rates

The first step is to convert the ASM concentrations for each vehicle tested in the roadside sample to FTP emission rates. The estimated FTP HC, CO, and NO_x emission rates in grams per mile can be estimated based on ASM concentration measurements for the roadside data and the models given in the December 25, 1999 report.

These models explain a large portion of the variance in the predicted FTP emission rates. This explained variance is calculated just as if the predicted FTP emissions rates were actual measurements. In addition to the explained variance, an unexplained variance is associated with the use of each of the FTP prediction equations. These unexplained variances are a result of the imperfect prediction of FTP emission rates from ASM concentrations. The unexplained variances must be accounted for when predicting the FTP emission rates of the fleet. These variances s^2_{unexp,ln_i} were quantified during model development. The unexplained variances in natural log space for the HC, CO, and NO_x models are 0.2467, 0.3523, and 0.1692, respectively.

Step 2. Calculate Mean and Variance of the Mean for Each Model Year

For the vehicles in a given model year *y*, the mean emission concentration $\bar{x}(y)$ and explained variance $s^2_{exp}(y)$ are given by:

$$\bar{x}(y) = \frac{\sum_{i=1}^{n(y)} x(y)_i}{n(y)}$$

$$s^2_{exp}(y) = \frac{\sum_{i=1}^{n(y)} \left(x(y)_\mathrm{i} - \bar{x}(y)\right)^2}{n(y) - 1}$$

where: *x(y)$_i$* = emissions value for the *i*th sampled vehicle in model year *y*
n(y) = the number of sampled vehicles in model year *y.*

The unexplained variance $\mathrm{s}^2_{\mathrm{unexp}}$ is calculated in linear space for each model year using the model year's mean FTP emission rate $\overline{\ln x(y)}$ in log space and the appropriate unexplained variance in log space $\mathrm{s}^2_{\mathrm{unexp,ln}}$ described in Step 1.

$$s^2_{unexp}(y) = \exp\left(2\,\overline{\ln x(y)} + 2\,s^2_{unexp,\,ln}\right) - \exp\left(2\,\overline{\ln x(y)} + s^2_{\mathbf{unexp,\,ln}}\right)$$

$$\text{where: } \overline{\ln x(y)} = \frac{\sum_{\mathrm{i=1}}^{\mathrm{n(y)}} \ln \mathrm{x\ (y)_i}}{n(y)}$$

Then, the explained and unexplained variances are summed and converted to the total error variance of the mean by dividing by the number of points in the sample for the model year under consideration.

The error variance of the mean for the emissions of the sampled vehicles for model year *y* is given by:

$$\mathrm{var}\left(\bar{x}(y)\right) = \frac{s^2(y)}{n(y)} = \frac{s^2_{unexp}\ (y) + s^2_{exp}\ (y)}{n(y)}$$

For the model year under consideration, the 95% confidence interval for the mean emissions of the fleet is given by:

$$\bar{x}(y) \pm 1.96 * \sqrt{\mathrm{var}\left(\bar{x}(y)\right)}$$

Step 3. Calculate Travel Fraction Weighted Mean and Variance of the Mean for the Fleet

The model year means and uncertainties for the fleet are then combined to arrive at average emissions estimates for the fleet. The weighting factors are the travel fractions for each model year.

The fleet average emissions $\bar{x}$ weighted by model year travel fractions tf_y is given by:

$$\bar{x} = \frac{\sum_{y=1}^{33} tf_y \, \bar{x}(y)}{\sum_{y=1}^{33} tf_y}$$

where $\bar{x}(y)$ is the average emissions for model year *y*.

The error variance of the fleet mean is given by:

$$\mathrm{var}\left(\bar{x}\right) = \frac{\sum_{y=1}^{33} tf_y^2 \, \mathrm{var}\left(\bar{x}(y)\right)}{\left(\sum_{y=1}^{33} tf_y\right)^2}$$

where $\mathrm{var}(\bar{x}(y))$ is the error variance of the mean for model year *y*.

Finally, the 95% confidence interval on the fleet mean emissions is given by:

$$\bar{x} \pm 1.96\sqrt{\mathrm{var}\left(\bar{x}\right)}$$

This confidence interval is an estimate of the precision of the average value. It does not include an estimate of any bias.

H. Results and Conclusions

Table III-5 shows the percent reduction in the emission rates after the Enhanced program was implemented. As can be seen, the percent reductions for HC and CO are approximately twice the reduction observed for NOx. In Chapter V, these results are used to determine emission reductions due to Enhanced I/M in "1994 SIP currency."

The NOx percent reduction is modest because during the time period that roadside data was being collected, the NOx cut points used to fail vehicles at Smog Check stations were set to identify "gross polluters" for NOx. Therefore, not many vehicles were failing for NOx and being repaired. However, since the roadside data was collected, BAR has significantly increased the stringency of the NOx cut points to levels specified in BAR regulations. Therefore, this analysis <u>understates</u> the actual emission reductions being achieved by the current I/M program; and, future analysis of roadside data should show significantly increased NOx reductions.

Table III-5
Roadside Results

	HC	**NOx**	**CO**
Before ASM [g/mi]	1.19	0.938	13.7
After ASM [g/mi]	1.03	0.886	12.1
Percent Reduction (Before to After)	13%	6%	12%